The Interplanetary Internet:
a communications infrastructure for Mars exploration

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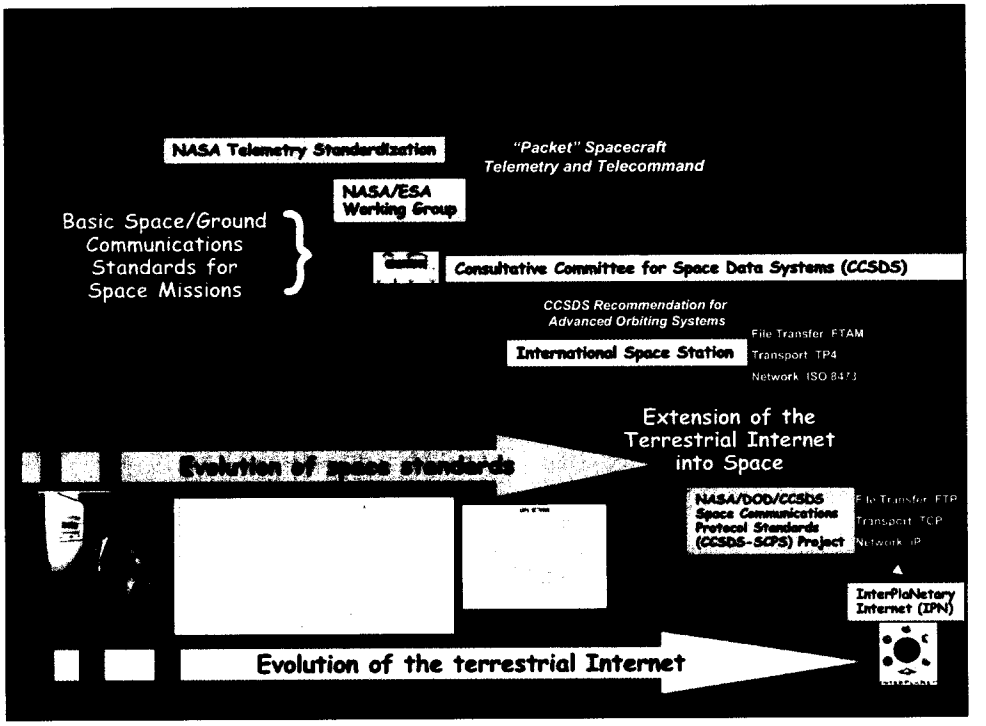
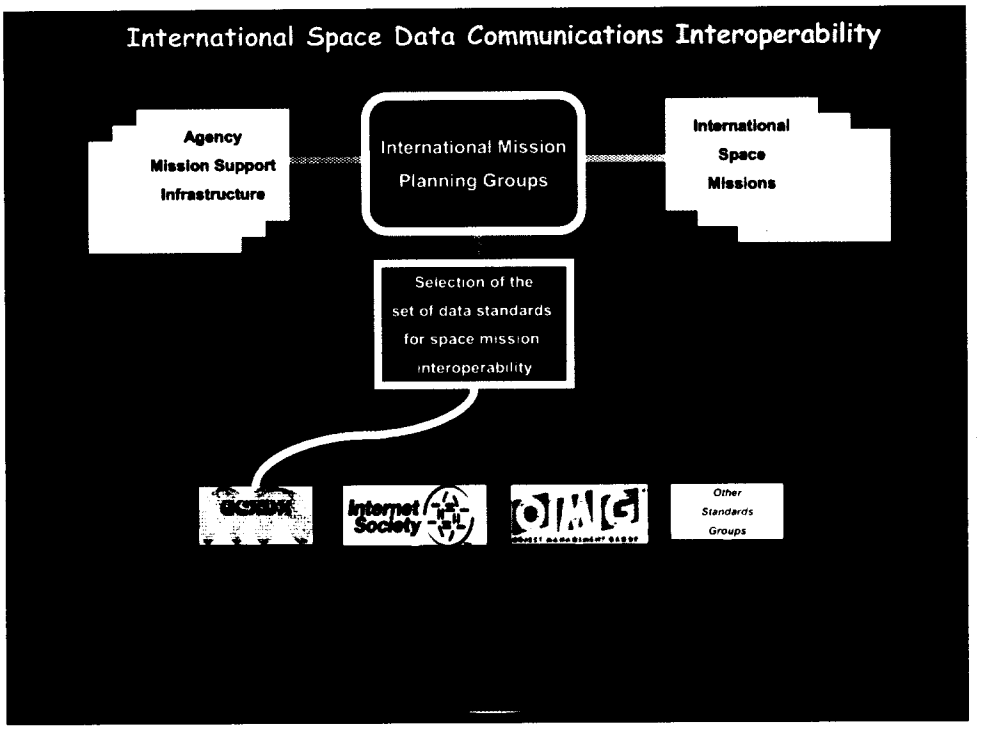
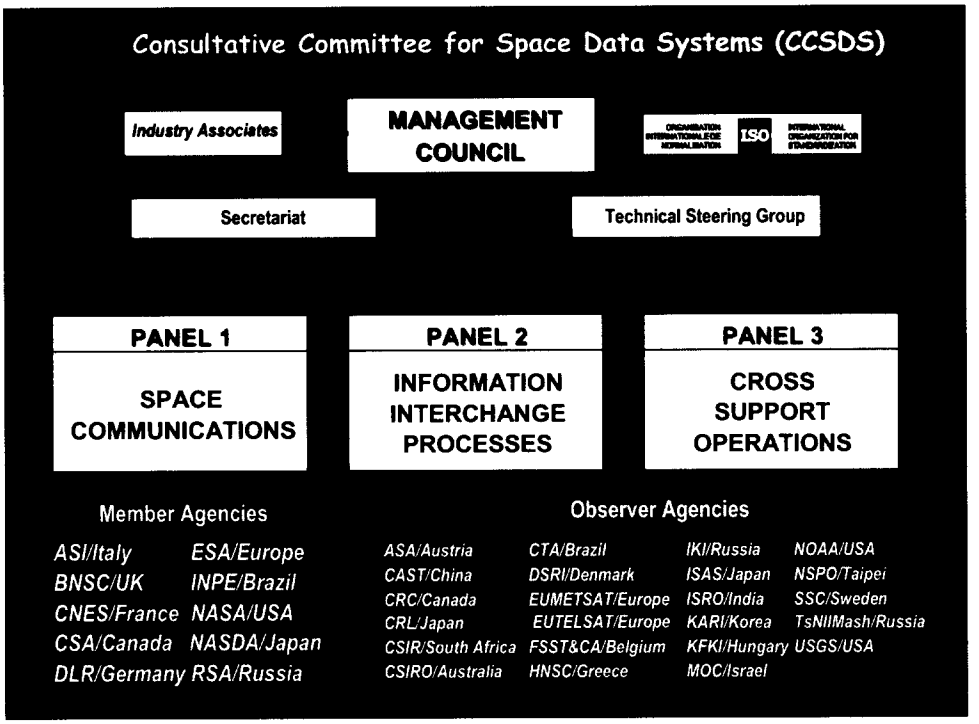
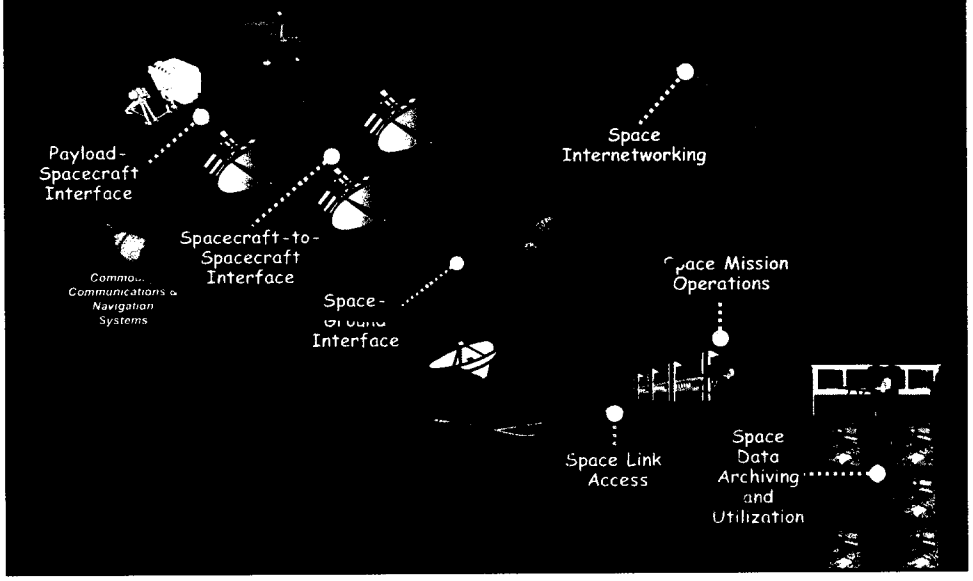



International Space Data Communications Interoperability
Agency
Mission Support
Infrastructure
International Mission
Planning Groups
International
Space
Missions
Selection of the
set of data standards
for space mission
interoperability
Internet
Society
Other
Standards
Groups


Consultative Committee for Space Data Systems (CCSDS)
Industry Associates
MANAGEMENT
COUNCIL
ISO
Secretariat
Technical Steering Group
PANEL 1
SPACE
COMMUNICATIONS
PANEL 2
INFORMATION
INTERCHANGE
PROCESSES
PANEL 3
CROSS
SUPPORT
OPERATIONS
Member Agencies
ASI/Italy
BNSC/UK
CNES/France
CSA/Canada
DLR/Germany
ESA/Europe
INPE/Brazil
NASA/USA
NASDA/Japan
RSA/Russia
Observer Agencies
ASA/Austria
CAST/China
CRC/Canada
CRL/Japan
CSIR/South Africa
CSIRO/Australia
CTA/Brazil
DSRI/Denmark
EUMETSAT/Europe
EUTELSAT/Europe
FSST&CA/Belgium
HNSC/Greece
IKI/Russia
ISAS/Japan
ISRO/India
KARI/Korea
KFKI/Hungary
MOC/Israel
NOAA/USA
NSPO/Taipei
SSC/Sweden
TsNIIMash/Russia
USGS/USA

The International Space Community: Data Systems Standardization Thrusts

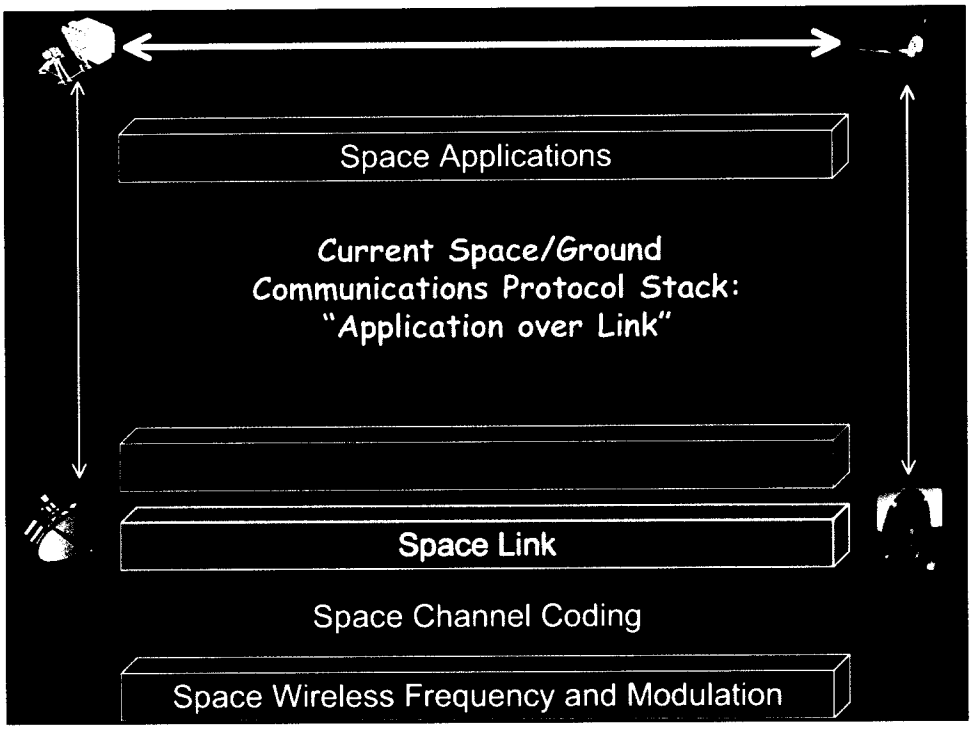


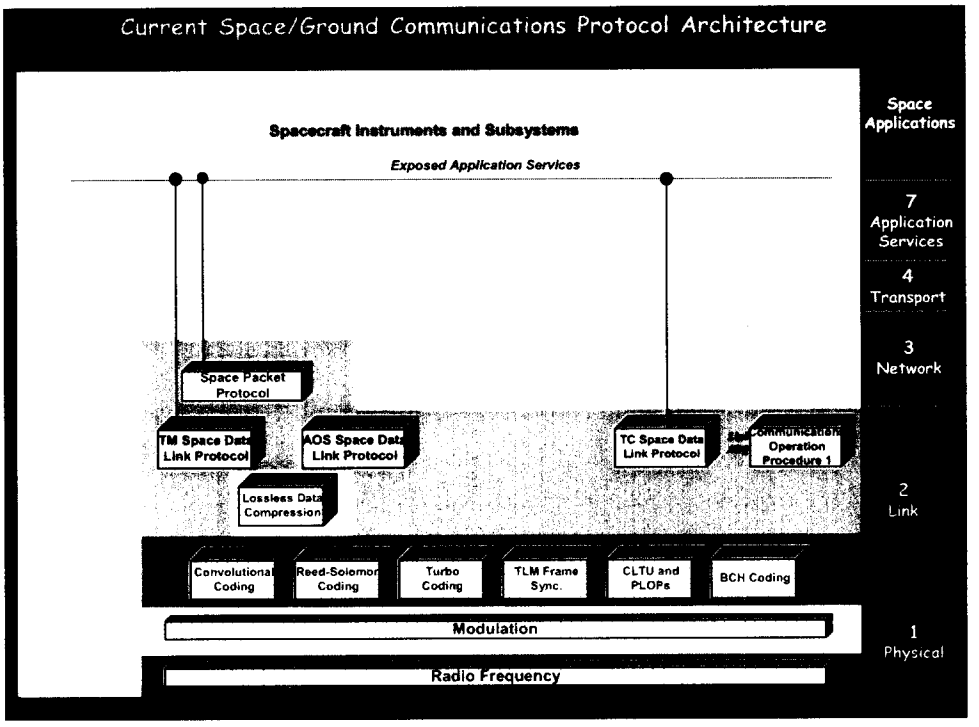
SPACE APPLICATIONS

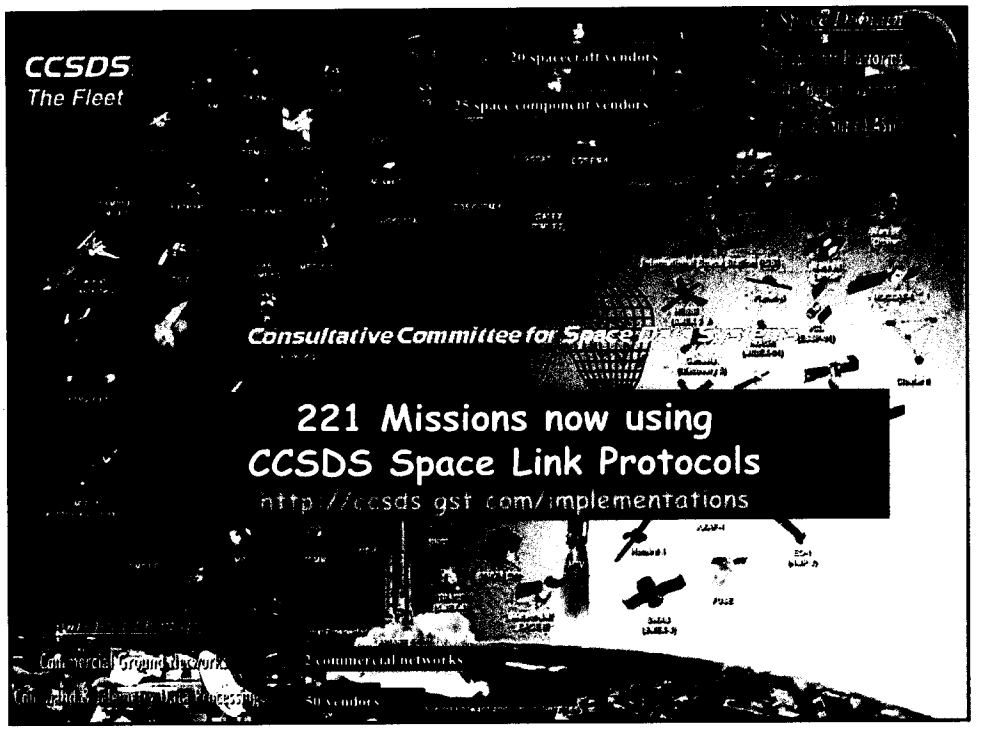
"Protocols" -
the standard rules by which a sender and a receiver conduct a dialog

- Space Application Services
- Space End-to-End Reliability
- Space End-to-End Security
- Space Networking
- **Space Link**
- Space Channel Coding
- Space Wireless Frequency and Modulation

Standard Layered Services


Space Applications
Current Space/Ground
Communications Protocol Stack:
"Application over Link"
Space Link
Space Channel Coding
Space Wireless Frequency and Modulation


Current Space/Ground Communications Protocol Architecture
Spacecraft Instruments and Subsystems
Exposed Application Services
Space Packet Protocol
TM Space Data Link Protocol
AOS Space Data Link Protocol
TC Space Data Link Protocol
Operation Procedure 1
Lossless Data Compression
Convolutional Coding
Reed-Solomon Coding
Turbo Coding
TLM Frame Sync.
CLTU and PLOPs
BCH Coding
Modulation
Radio Frequency
Space Applications
7 Application Services
4 Transport
3 Network
2 Link
1 Physical



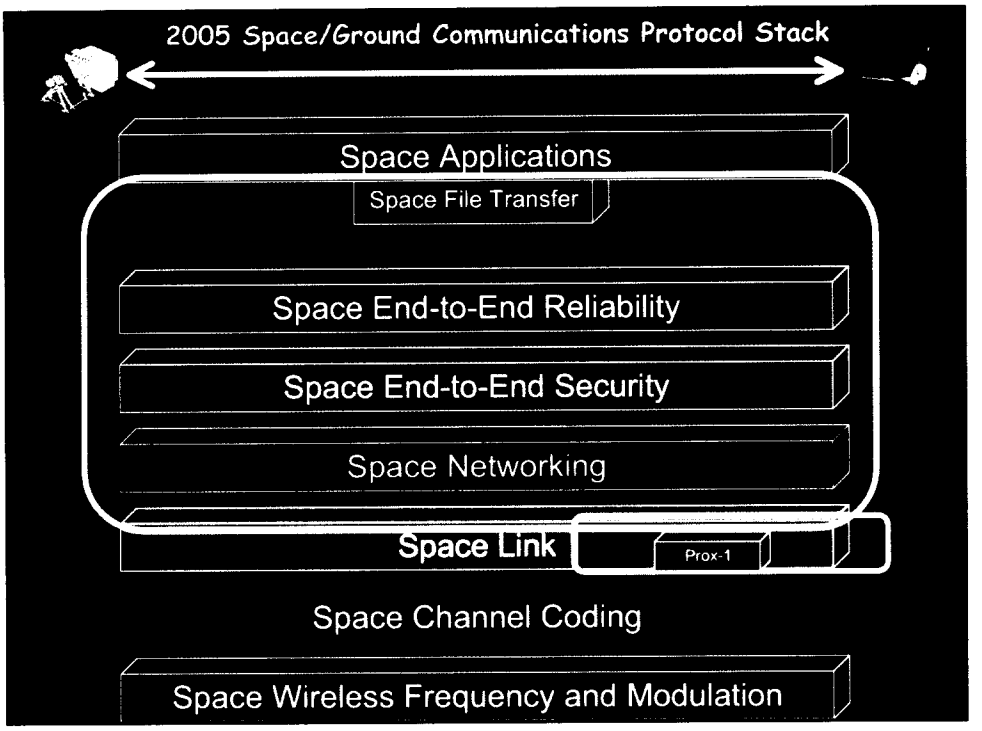
The Next Few Years

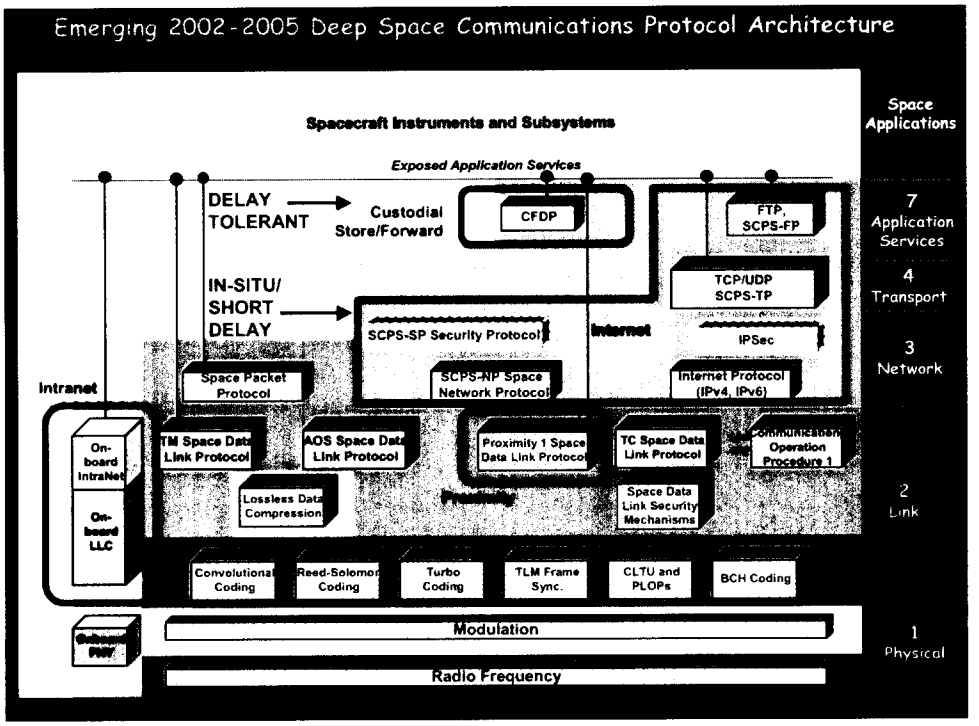
- In the next few years (2002-2005) we will evolve and migrate to add:

1. A new flavor of CCSDS space link protocol for communicating at short range, e.g., between spacecraft in a constellation or between Mars orbiters and surface assets
   - CCSDS "Proximity 1" protocol

2. A more networked set of upper layer standards:
   - CCSDS File Delivery Protocol (CFDP) for disconnected environments
     - Long delays, episodic connectivity
     - Custodial store-and-forward mode
     - Most missions will use this for routine space/ground data hauling
   - Internet suite for richly connected in-situ environments
     - Short delays, stable connectivity
     - Instantaneous end-end dialog
     - Onboard a spacecraft; near-Earth; on and around another planet

3. Standardized onboard networking


2005 Space/Ground Communications Protocol Stack
Space Applications
Space File Transfer
Space End-to-End Reliability
Space End-to-End Security
Space Networking
Space Link
Prox-1
Space Channel Coding
Space Wireless Frequency and Modulation


Emerging 2002-2005 Deep Space Communications Protocol Architecture
Spacecraft Instruments and Subsystems
Space Applications
Exposed Application Services
DELAY TOLERANT
Custodial Store/Forward
CFDP
FTP, SCPS-FP
7 Application Services
IN-SITU/ SHORT DELAY
TCP/UDP SCPS-TP
4 Transport
SCPS-SP Security Protocol
Internet
IPSec
3 Network
Intranet
Space Packet Protocol
SCPS-NP Space Network Protocol
Internet Protocol (IPv4, IPv6)
On-board IntraNet
On-board LLC
TM Space Data Link Protocol
AOS Space Data Link Protocol
Proximity 1 Space Data Link Protocol
TC Space Data Link Protocol
Communication Operation Procedure 1
Lossless Data Compression
Space Data Link Security Mechanisms
2 Link
Convolutional Coding
Reed-Solomon Coding
Turbo Coding
TLM Frame Sync.
CLTU and PLOPs
BCH Coding
Modulation
Radio Frequency
1 Physical

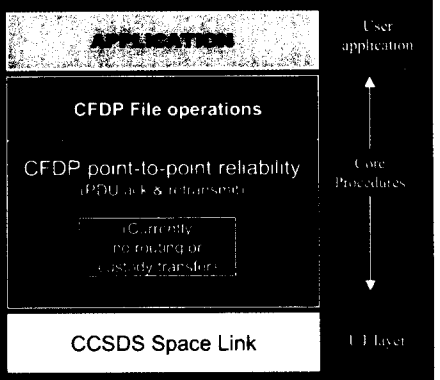
CFDP - CCSDS File Delivery Protocol

- The CCSDS File Delivery Protocol is an internationally standardized mechanism to deliver files of space mission data end-to-end through a space network via a series of store-and-forward hops, using custody transfer techniques
- The current CFDP ("Build 1") provides non-routed, non-custodial delivery through a single hop.

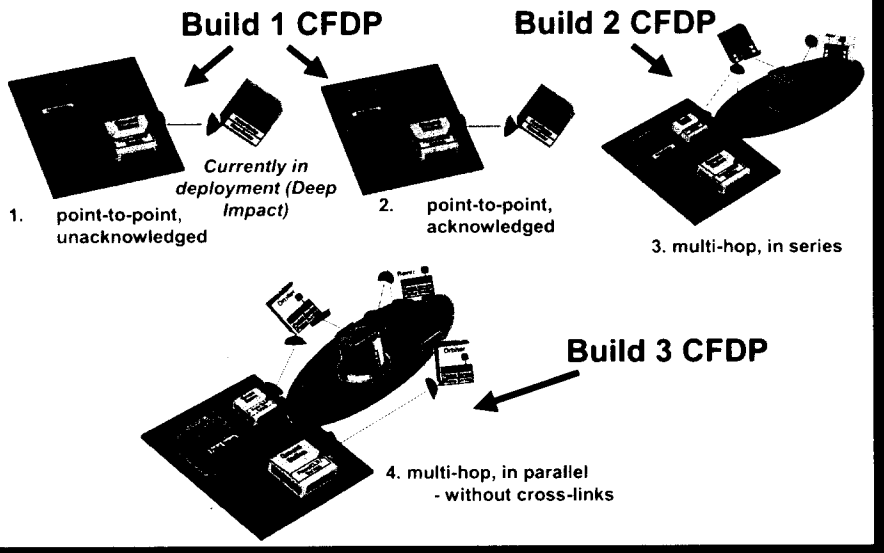
- the user application
- file handling mechanisms

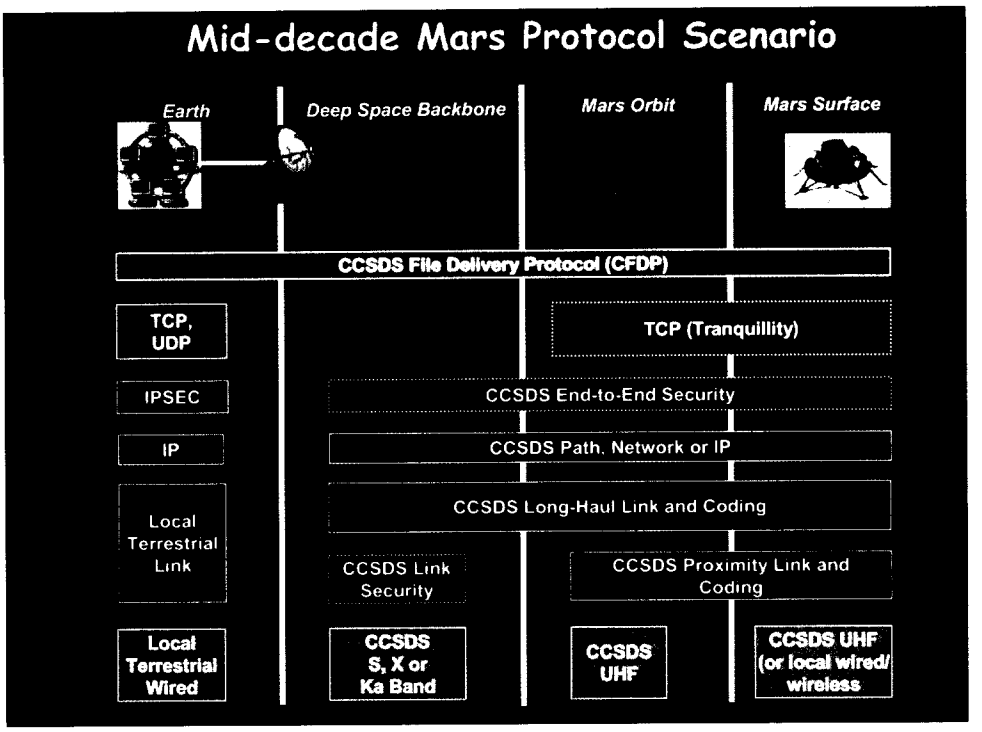
+

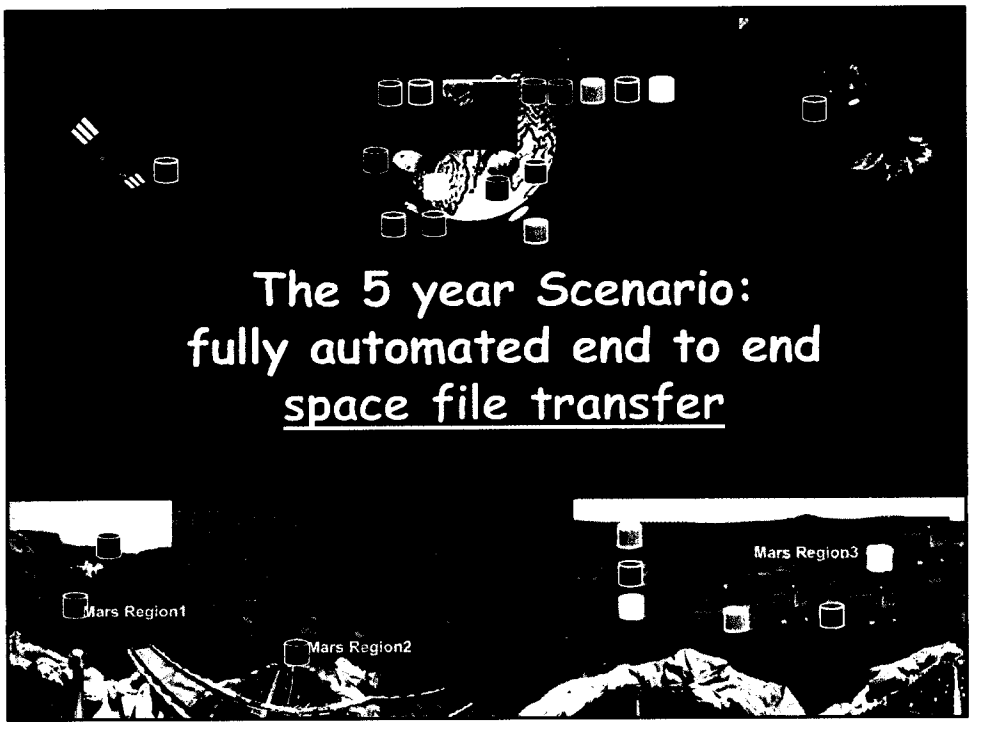
- point-to-point reliability mechanisms
- underlying space link unit data transfer services



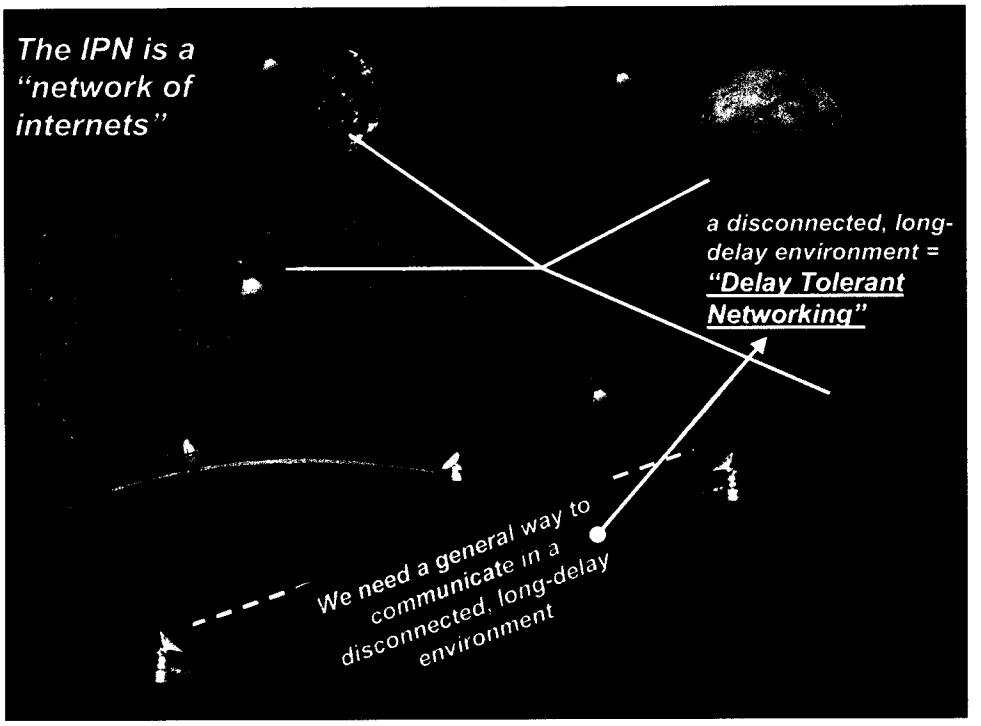
CFDP Operations Scenarios

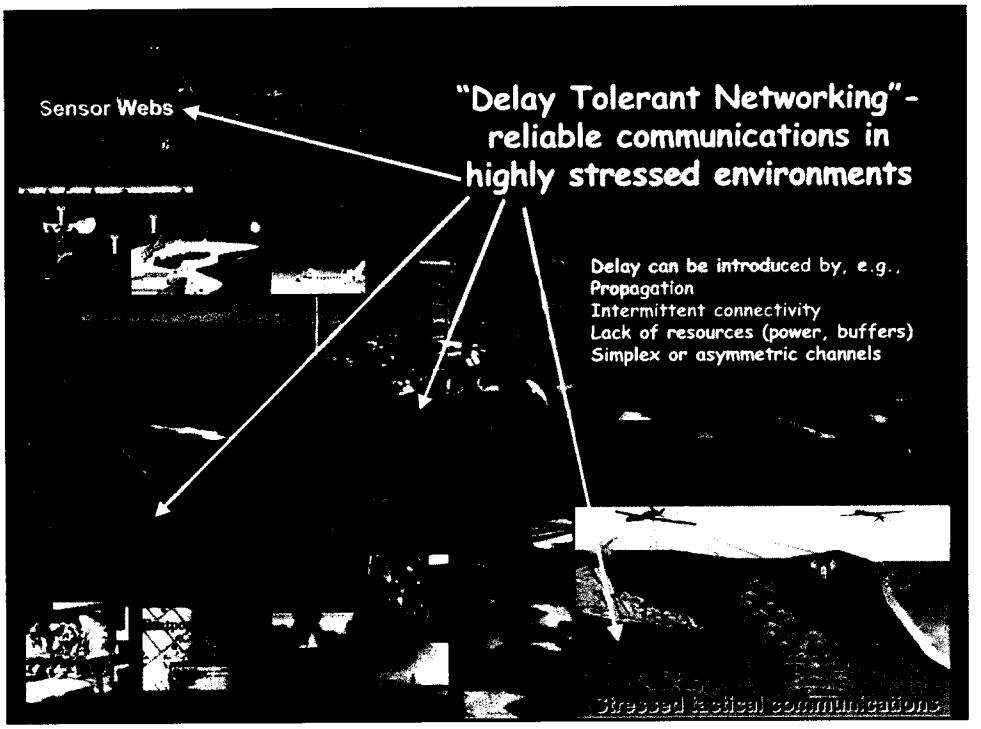


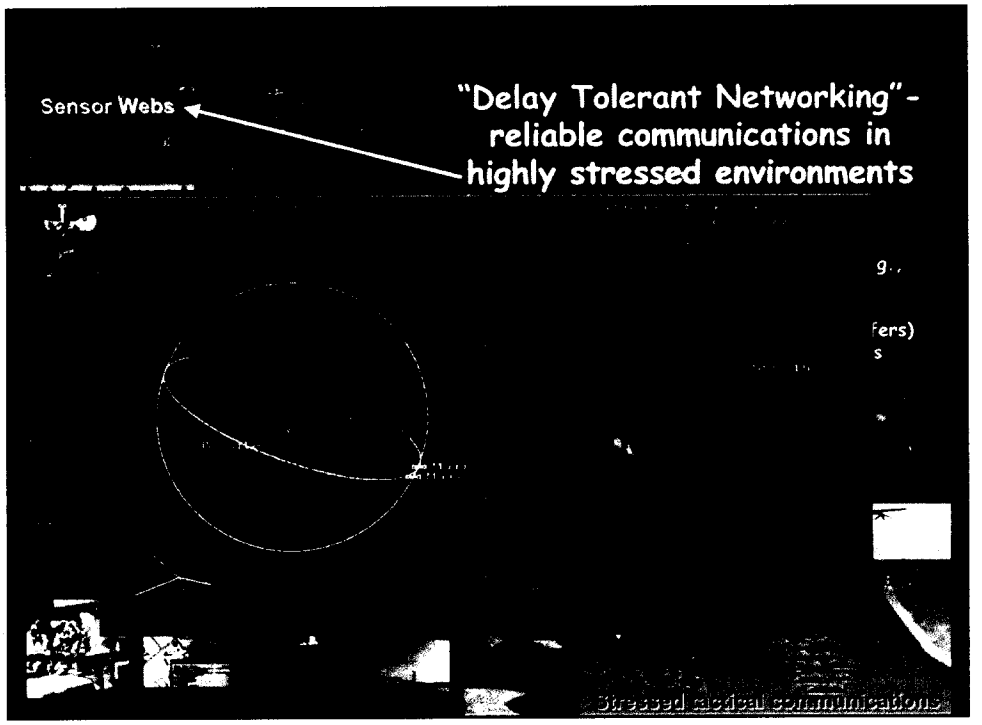

Mid-decade Mars Protocol Scenario
Earth
Deep Space Backbone
Mars Orbit
Mars Surface
CCSDS File Delivery Protocol (CFDP)
TCP, UDP
TCP (Tranquillity)
IPSEC
CCSDS End-to-End Security
IP
CCSDS Path, Network or IP
Local Terrestrial Link
CCSDS Long-Haul Link and Coding
CCSDS Link Security
CCSDS Proximity Link and Coding
Local Terrestrial Wired
CCSDS S, X or Ka Band
CCSDS UHF
CCSDS UHF (or local wired/ wireless


The 5 year Scenario:
fully automated end to end
space file transfer
Mars Region1
Mars Region2
Mars Region3

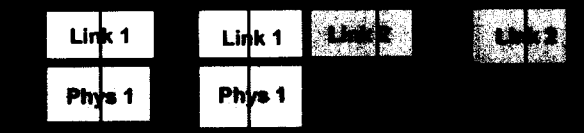

• Our missions are increasingly moving from point-to-point to networked architectures
• Internal to each spacecraft
• On and around other planets
• Just like the terrestrial Internet, standardized space networking allows us to build low-cost, reusable infrastructure that can be shared by many diverse users


The IPN is a "network of internets"
a disconnected, long-delay environment = "Delay Tolerant Networking"
We need a general way to communicate in a disconnected, long-delay environment


Sensor Webs
"Delay Tolerant Networking"-
reliable communications in
highly stressed environments
Delay can be introduced by, e.g.,
Propagation
Intermittent connectivity
Lack of resources (power, buffers)
Simplex or asymmetric channels
Stressed tactical communications

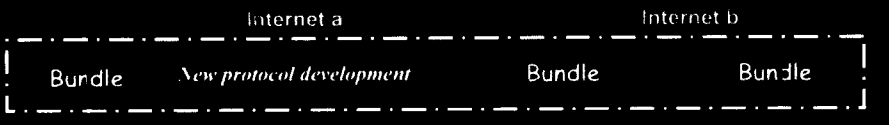

Sensor Webs
"Delay Tolerant Networking"-
reliable communications in
highly stressed environments
g.,
fers)
s
Stressed tactical communications

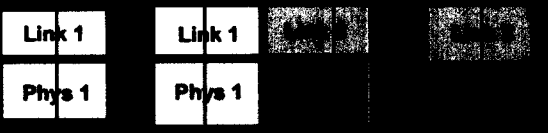
The Internet: a Network of low delay, connected Sub-Networks



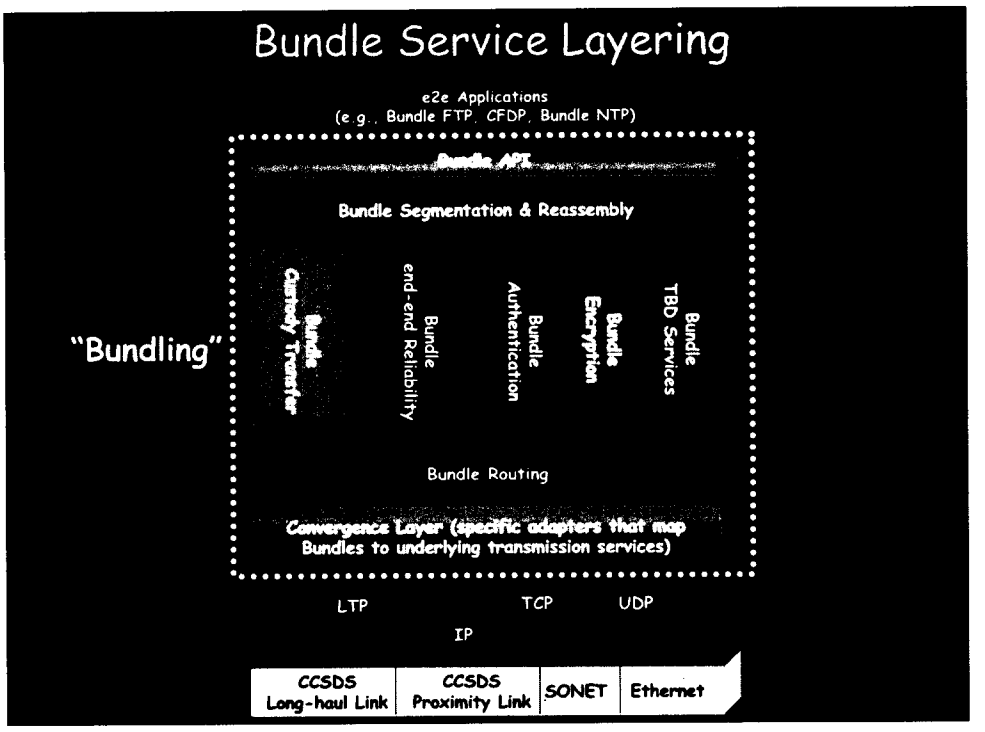
Subnet 1 Subnet 2 Subnet 3

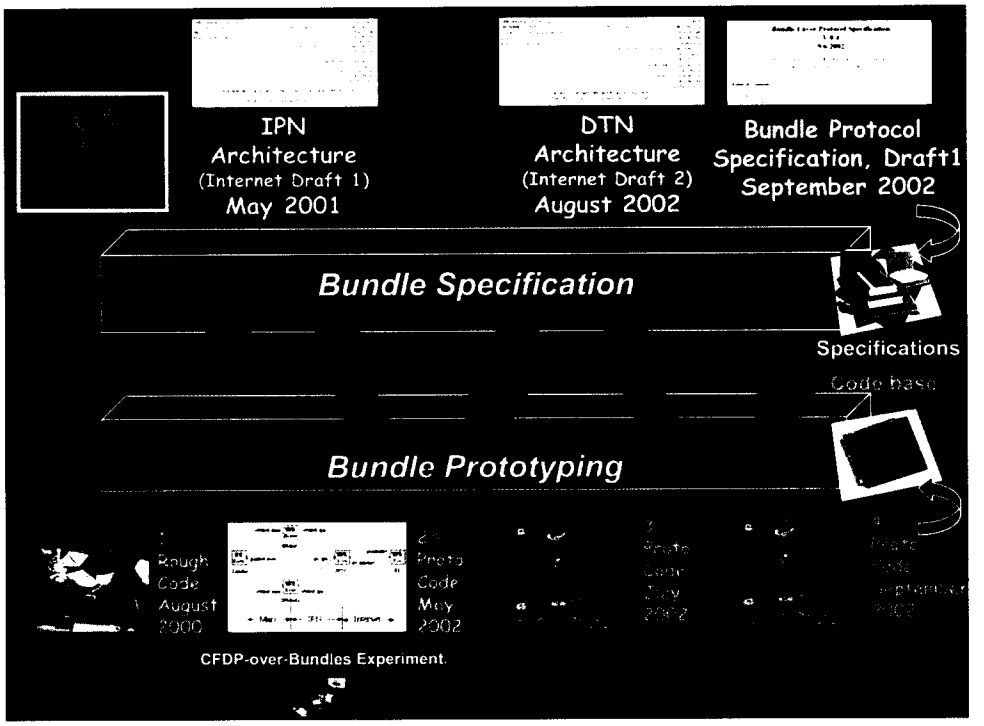
Bundles: A Store and Forward Application Overlay

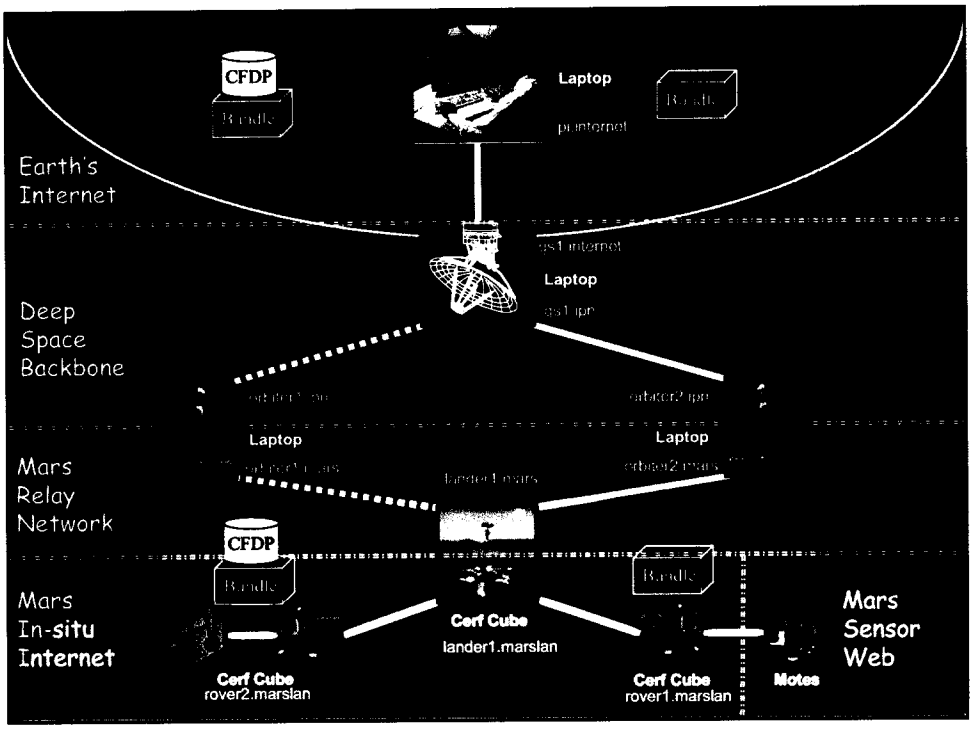


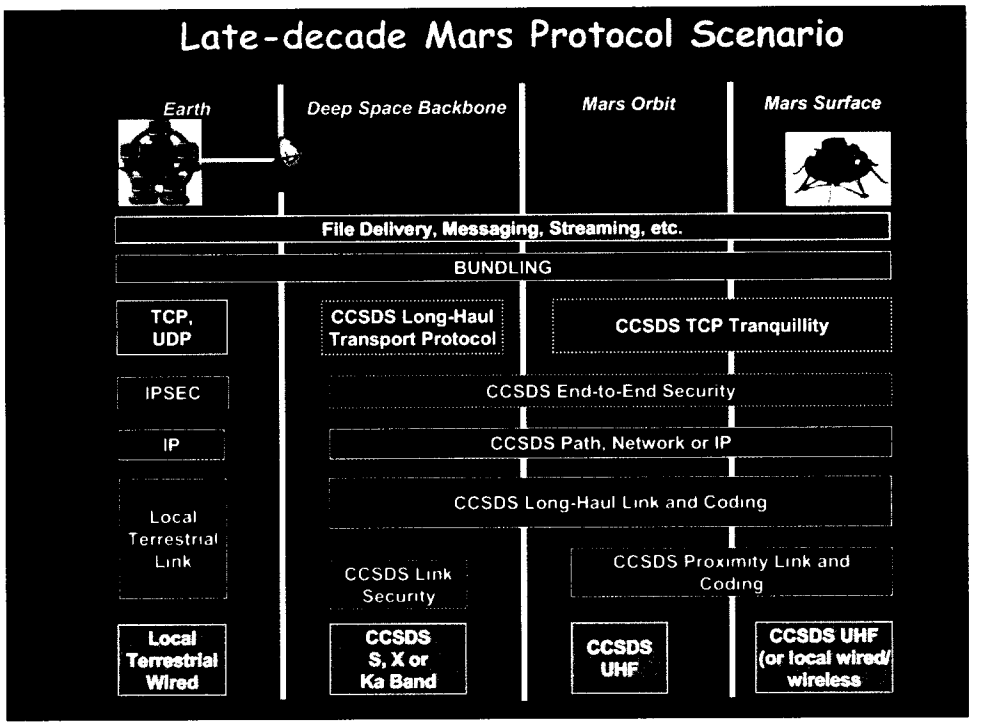


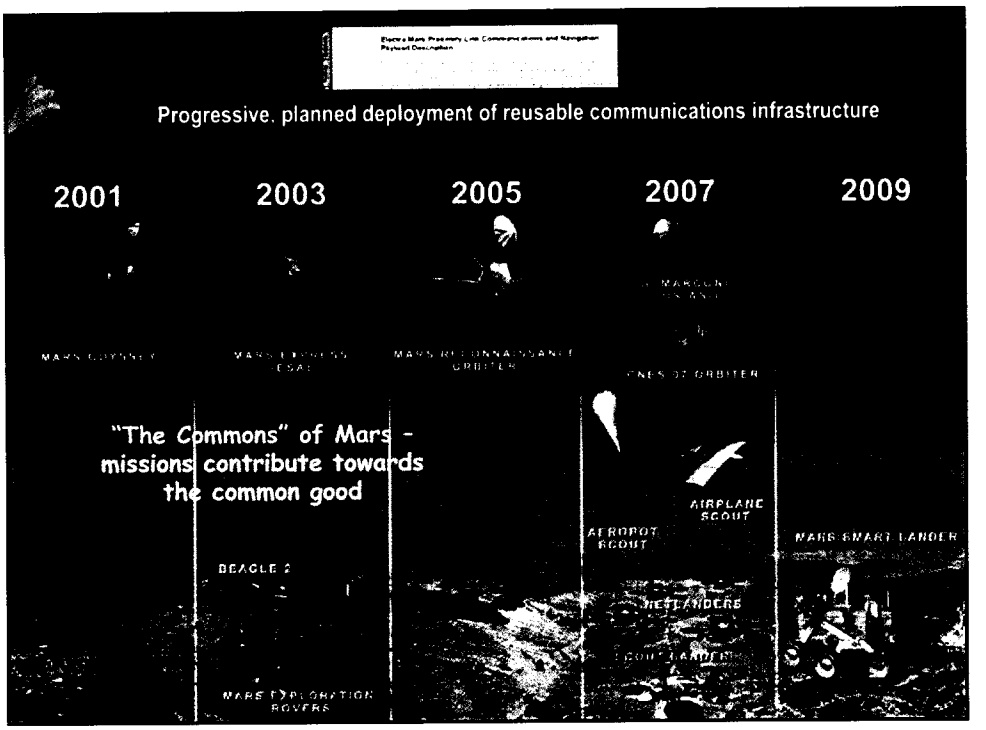
A "network of internets" spanning dissimilar environments


Bundle Service Layering
e2e Applications
(e.g., Bundle FTP, CFDP, Bundle NTP)
Bundle API
Bundle Segmentation & Reassembly
"Bundling"
Bundle Custody Transfer
Bundle end-end Reliability
Bundle Authentication
Bundle Encryption
Bundle TBD Services
Bundle Routing
Convergence Layer (specific adapters that map Bundles to underlying transmission services)
LTP
TCP
UDP
IP
CCSDS Long-haul Link
CCSDS Proximity Link
SONET
Ethernet


IPN Architecture (Internet Draft 1) May 2001
DTN Architecture (Internet Draft 2) August 2002
Bundle Protocol Specification, Draft1 September 2002
Bundle Specification
Specifications
Code base
Bundle Prototyping
Rough Code August 2000
Proto Code May 2002
CFDP-over-Bundles Experiment


CFDP
Bundle
Laptop
Earth's Internet
Deep Space Backbone
Laptop
Laptop
Mars Relay Network
CFDP
Bundle
Bundle
Mars In-situ Internet
Cerf Cube
rover2.marslan
Cerf Cube
lander1.marslan
Cerf Cube
rover1.marslan
Motes
Mars Sensor Web


Late-decade Mars Protocol Scenario
Earth
Deep Space Backbone
Mars Orbit
Mars Surface
File Delivery, Messaging, Streaming, etc.
BUNDLING
TCP, UDP
CCSDS Long-Haul Transport Protocol
CCSDS TCP Tranquillity
IPSEC
CCSDS End-to-End Security
IP
CCSDS Path, Network or IP
Local Terrestrial Link
CCSDS Long-Haul Link and Coding
CCSDS Link Security
CCSDS Proximity Link and Coding
Local Terrestrial Wired
CCSDS S, X or Ka Band
CCSDS UHF
CCSDS UHF (or local wired/ wireless


Progressive, planned deployment of reusable communications infrastructure
2001
2003
2005
2007
2009
"The Commons" of Mars - missions contribute towards the common good
BEAGLE 2
MARS EXPLORATION ROVERS
AIRPLANE SCOUT
AEROBOT SCOUT
NETLANDERS
MARS SMART LANDER